N89-19250

UNSTEADY TRANSONIC VISCOUS-INVISCID INTERACTION USING EULER AND BOUNDARY-LAYER EQUATIONS*

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*This research was sponsored by NASA Langley Research Center. It is a report on work in progress.

OBJECTIVES

This list is obvious for a symposium on transonic unsteady aerodynamics. The last three are the most difficult to achieve. Turbulence is in its usual state of affairs.

- VISCOUS-INVISCID INTERACTION
- TRANSONIC
- UNSTEADY
- TURBULENT
- THREE-DIMENSIONAL
- EFFICIENT
- ROBUST

APPROACH

The Euler code is one we've used extensively for some time now. The boundary-layer code solves the three-dimensional, compressible, unsteady, mean flow kinetic energy integral boundary-layer equations in the direct mode. Inviscid-viscous coupling is handled using porosity boundary conditions.

- EULER EQUATIONS
  - IMPLICIT
  - FINITE VOLUME
  - UNSTEADY
  - FLUX-VECTOR SPLIT
  - THREE-DIMENSIONAL

- BOUNDARY-LAYER EQUATIONS
  - COMPRESSIBLE
  - THREE-DIMENSIONAL
  - UNSTEADY
  - MEAN FLOW KINETIC ENERGY
  - INTEGRAL
  - DIRECT

OUTLINE OF RESULTS

This slide outlines the order of the results to follow. Steady-state results are considered first to validate the basic inviscid and viscous codes, followed by the unsteady results that have been obtained to date.

- STEADY-STATE
  - 3-D EULER, 2-D BOUNDARY-LAYER (WING-FUSELAGE)
  - 3-D EULER, 3-D BOUNDARY-LAYER (WING)
- UNSTEADY
  - 3-D EULER, 3-D BOUNDARY-LAYER (WING)
  - 3-D EULER, 3-D BOUNDARY-LAYER (QUASI-STEADY AIRFOIL)
  - 3-D NAVIER-STOKES (AIRFOIL)

A two-dimensional steady version of the turbulent boundary-layer code was used with the three-dimensional Euler code in a strip-theory fashion to compute the flow about the supercritical Pathfinder wing with fuselage. The results are shown in Figure 1. These results are included simply to illustrate the type of results that might be obtained using the boundary-layer in a strip-theory fashion. The results were obtained by Dr. Keith Koenig, Mississippi State, under a NASA Langley grant.

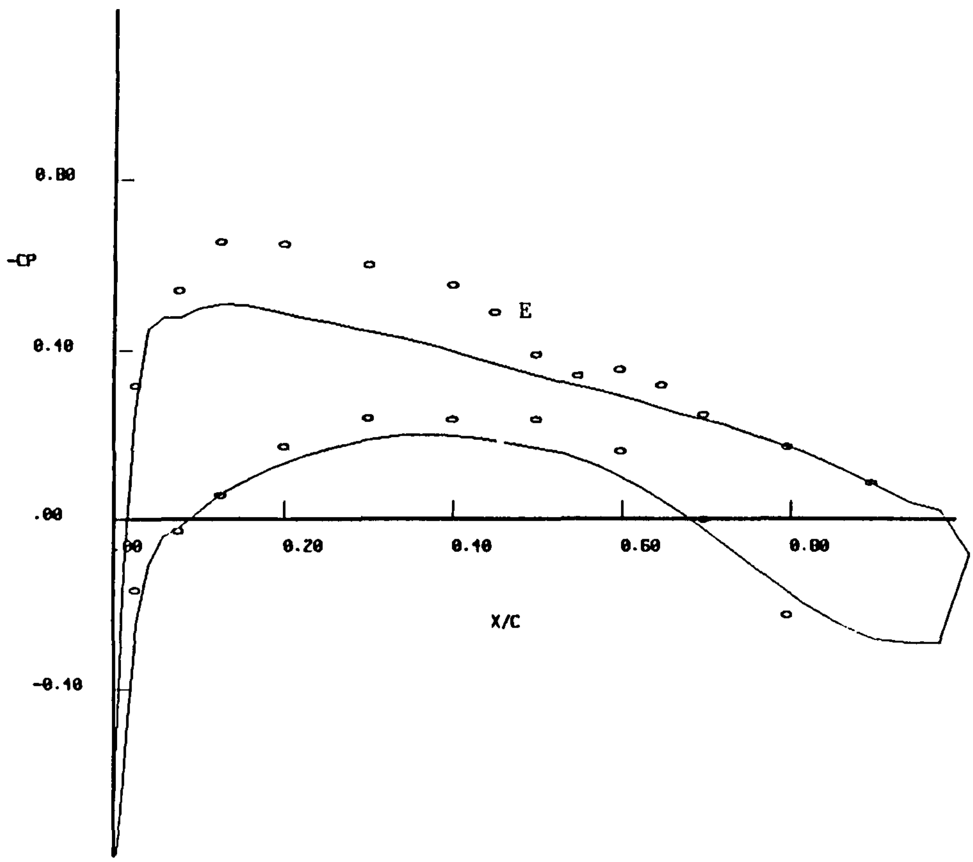

Figure 1a. Section pressure distribution, M_∞=0.7, α=2°, Re=5.3*10^6;
E = experiment, 13.1% span; ———— , viscous, 15% span.

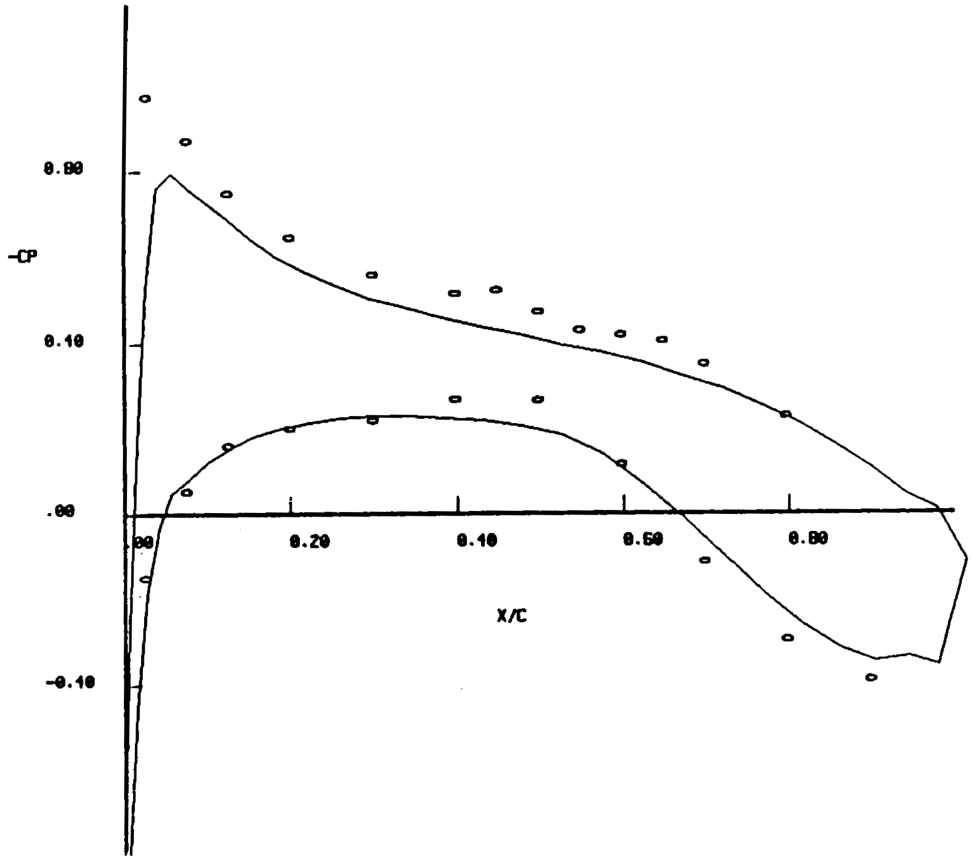

Figure 1b. E, 29.2%; calculation, 25%.

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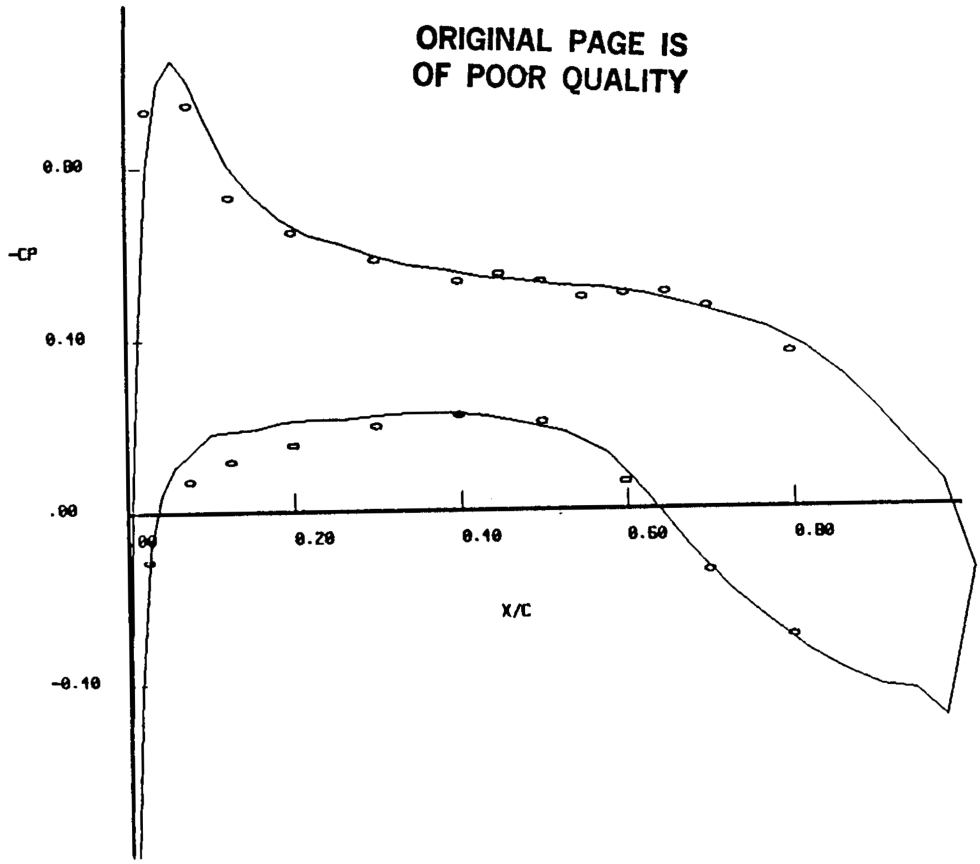

Figure 1c. E, 43.2%; calculation, 45%.

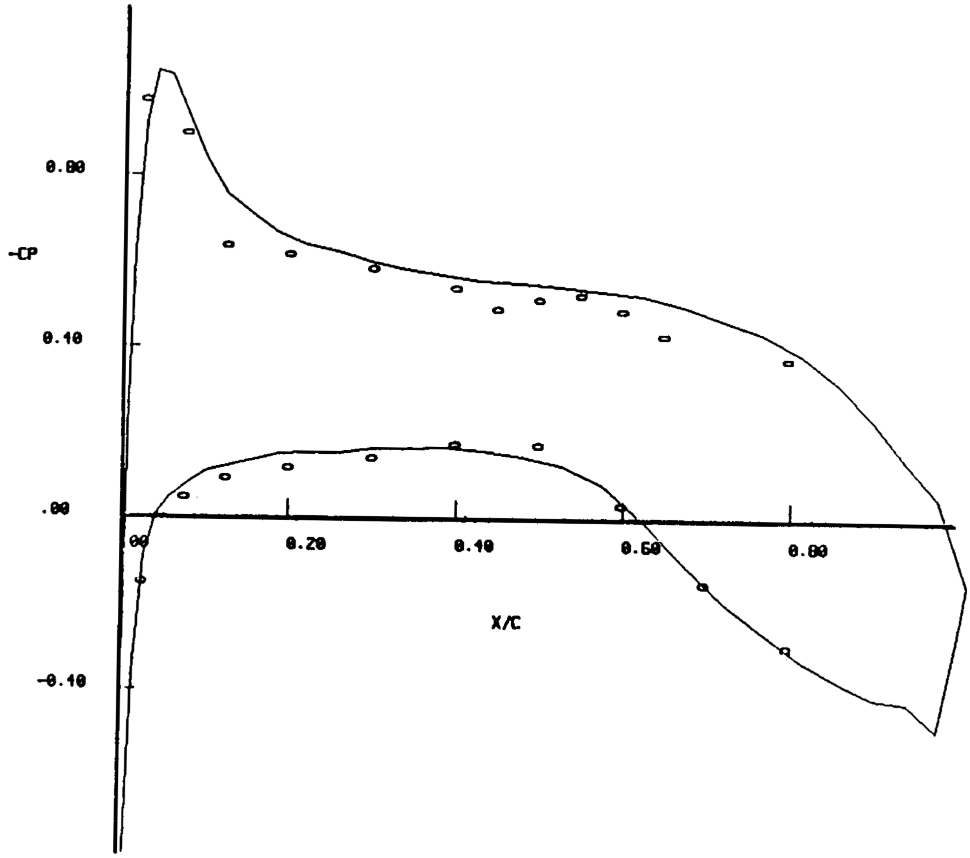

Figure 1d. E, 64%, calculation, 65%.

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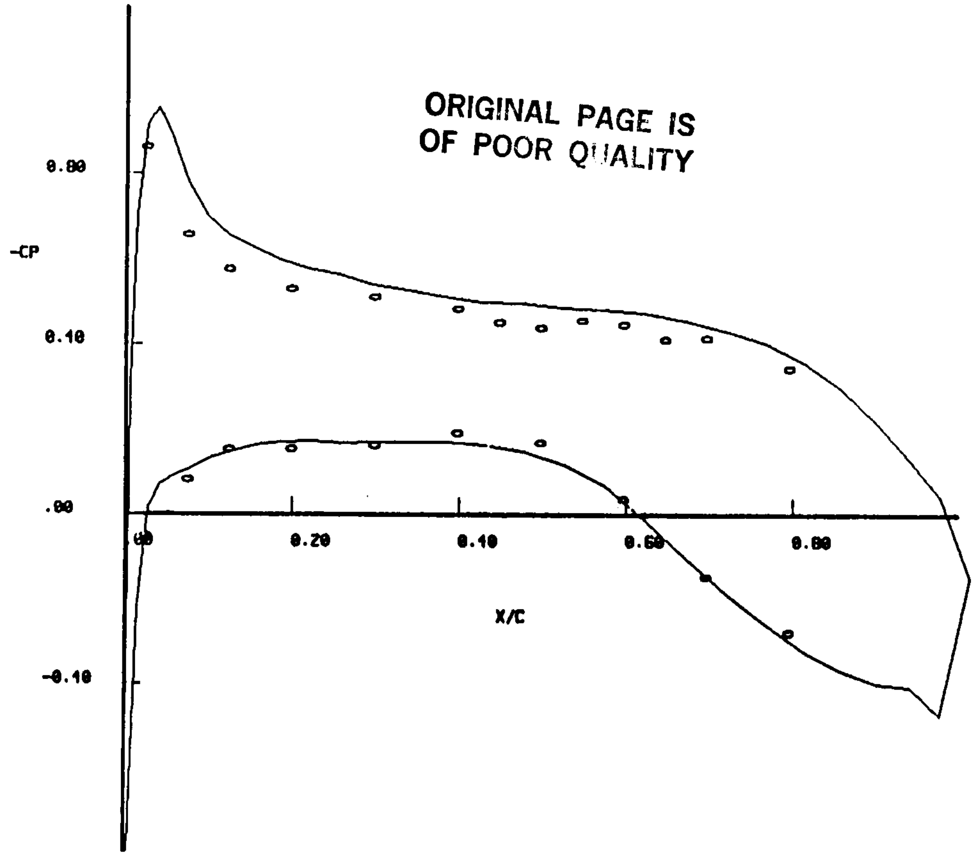


Figure 1e. E, 84%; calculation, 84%.

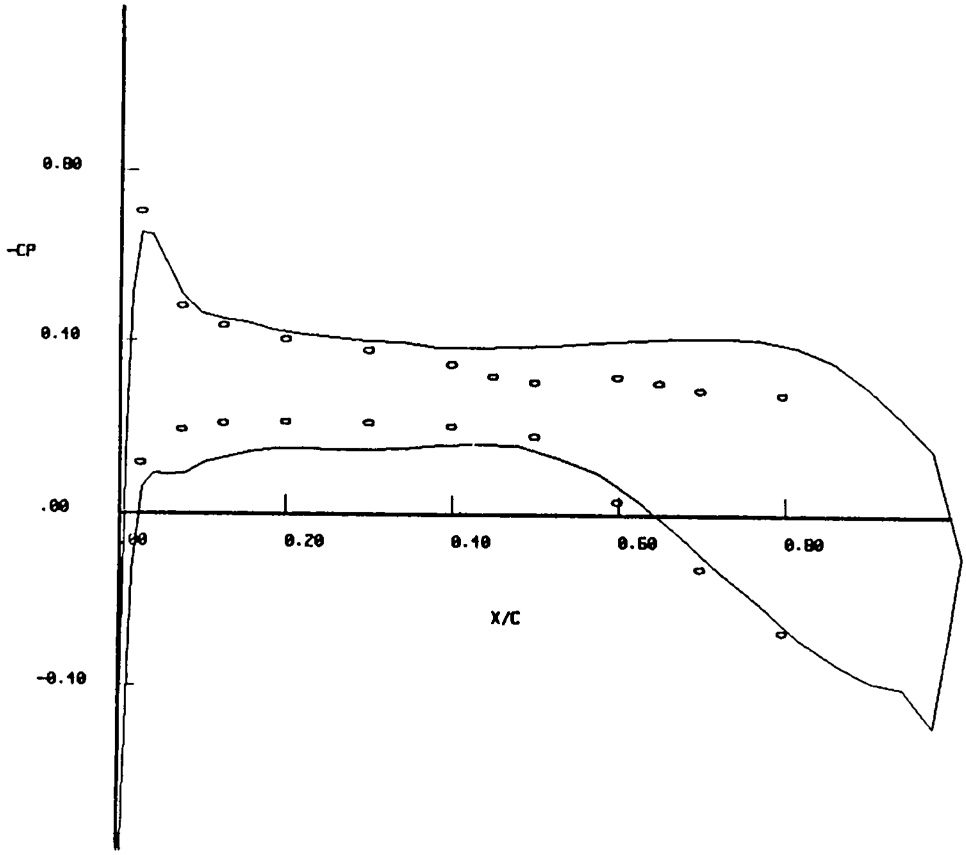


Figure 1f. E, 96.1%; calculation, 95%.

A steady-state interactive solution using the three-dimensional unsteady Euler and boundary-layer codes was obtained for the ONERA M6 wing. The streamwise momentum thickness and shape factor distributions at about fifty percent semi-span location are compared in Figure 2 with the calculations of Schmitt, Destarac, and Chavmet. An isolated experimental data point at sixty percent chord location is also shown.

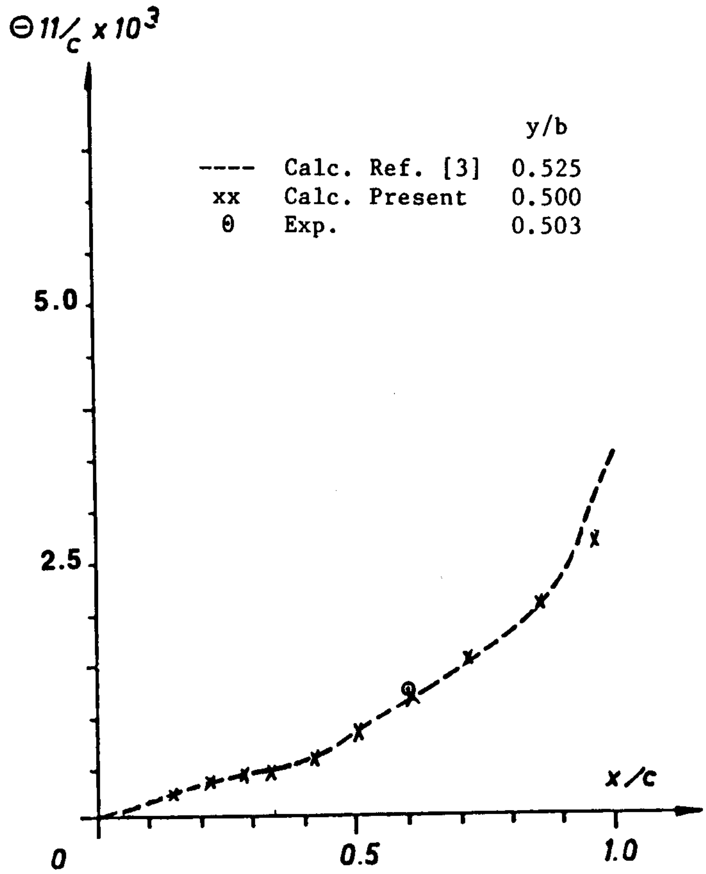


Fig. 2a. Boundary layer characteristics on the upper surface of the ONERA M6 wing. M=0.84, Re_c=11.7x10^6, α=3°.

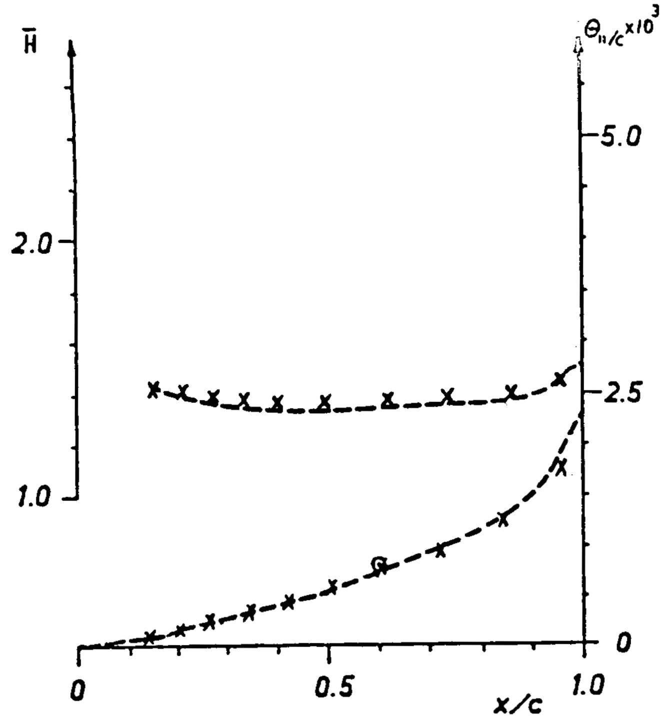
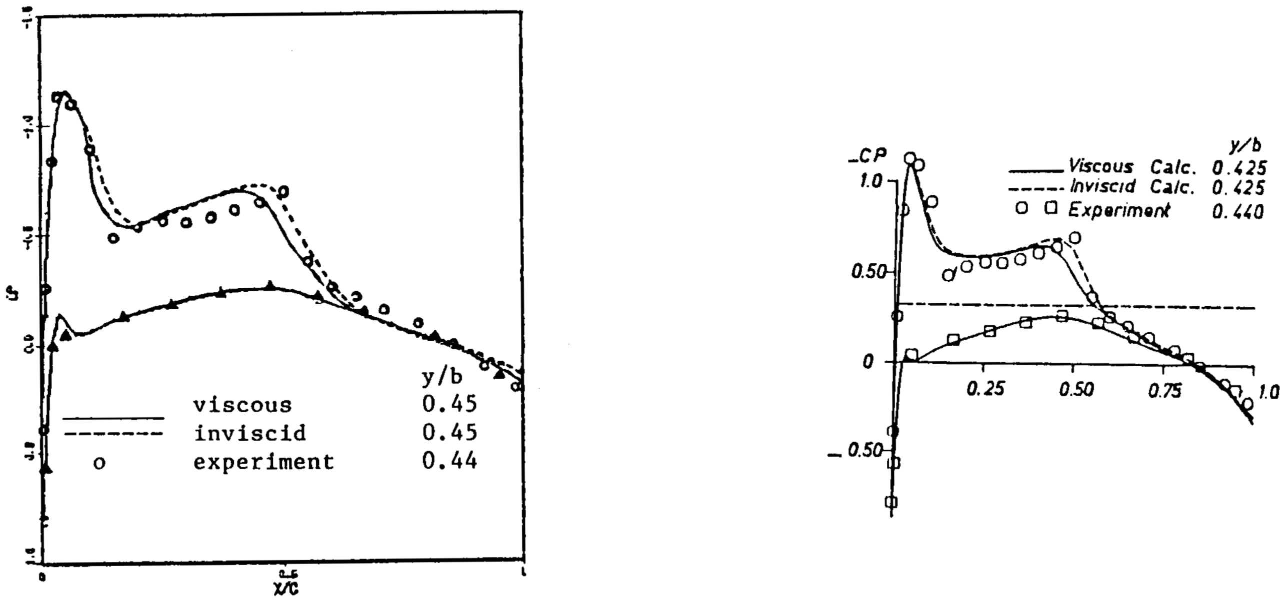


Fig. 2b. Boundary layer characteristics on the lower surface of the ONERA M6 wing. M=0.84, $Re_c=11.7 \times 10^6$, $\alpha=3°$.

Surface pressure distributions for the same solution as shown in Figure 2 are compared in Figure 3 with the computations of Schmitt, et al., and experimental data at about forty-five percent semi-span location. The computations of Schmitt et al. used potential flow and a steady state three-dimensional integral boundary-layer code.



(a) Present calculation (b) Ref. [3]

Fig. 3. Steady pressure distribution on the ONERA M6 Wing. M=0.84, α=3°

A complete three-dimensional unsteady viscous-inviscid interaction solution was obtained on a relatively coarse grid for the ONERA M6 wing as shown in Figures 4 through 6. The wing was oscillated in pitch ± 2 degrees (mean angle of attack was 0°) about the mid-chord at a reduced frequency of 0.3. For this case there was little viscous effect. Figure 4 shows unsteady viscous and inviscid surface pressure distributions at forty-five percent semi-span location. It is a snapshot at $\alpha = 1.94°$.

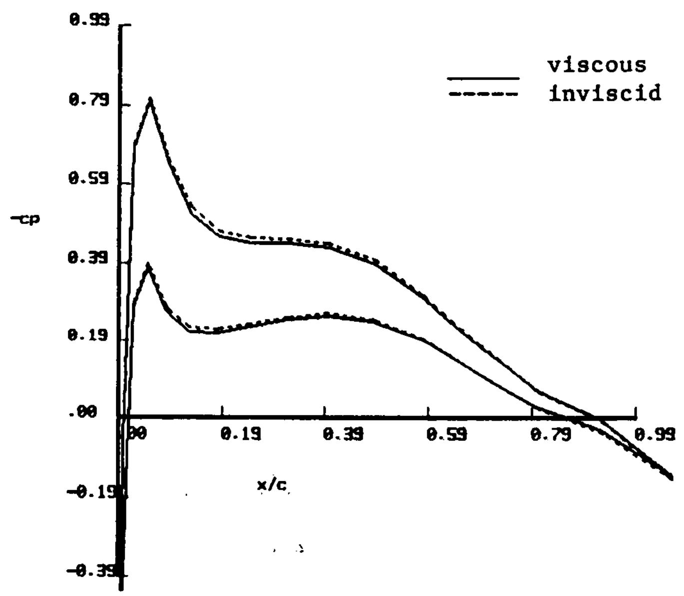


Fig. 4. Unsteady pressure distributions on the ONERA M6 wing at $M=0.84$, $k=0.3$, $\alpha=1.94°$, and $y/b=0.45$. Pitch oscillation about mid-chord $-2° < \alpha < 2°$.

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Figure 5 shows the phase shift of the viscous solution described on Figure 4.

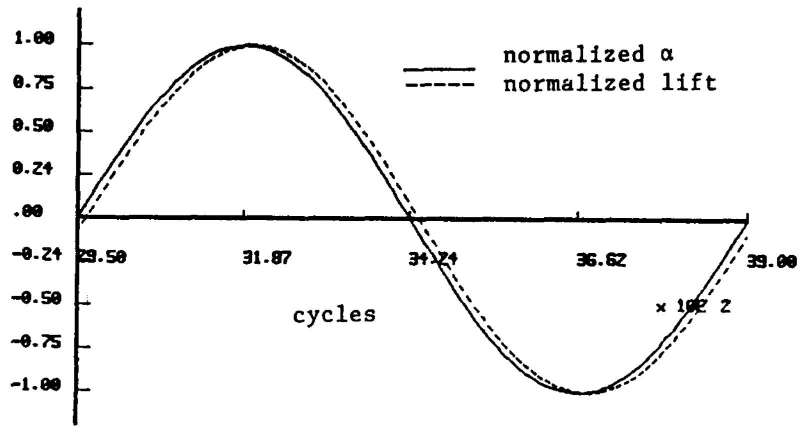

Fig. 5. Phase shift of the ONERA M6 wing lift coefficient (viscous solution). Pitch oscillation. $M=0.84$, $k=0.3$, $-2° \leq \alpha \leq 2°$.

Figure 6 shows the viscous and inviscid results of drag coefficient and number of supersonic cells for the computation described on Figure 4.

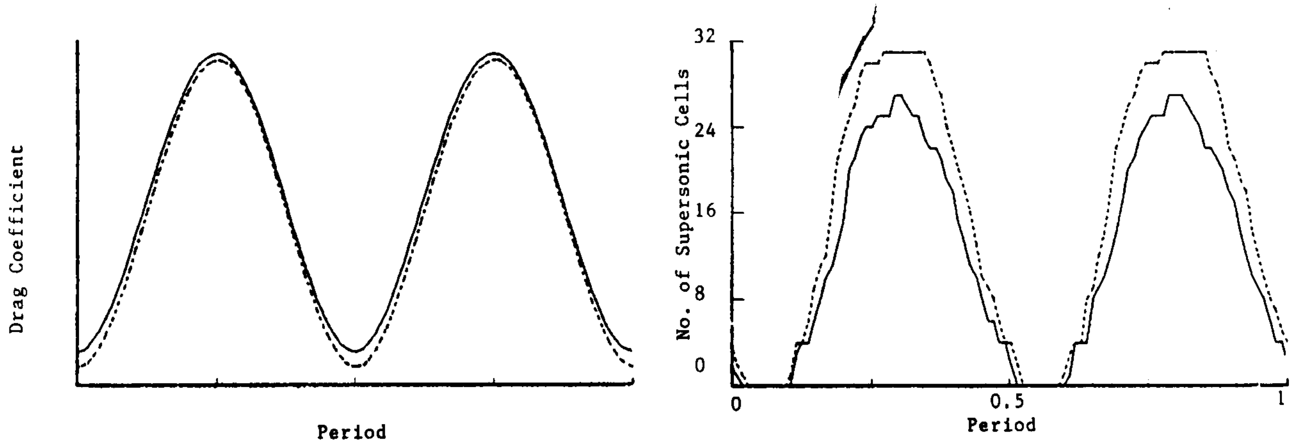

Fig. 6. Drag coefficient and number of supersonic cells. ONERA M6 wing pitch oscillation. M=0.84, k=0.3, -2° < α < 2°.

Figure 7 is a plot of normalized lift and drag verses period for an NACA 0012 airfoil at $M_\infty = 0.776$, Reynolds number of 23.7×10^6, oscillating ± 1 degree in pitch about the quarter-chord point at a reduced frequency of 0.3 using quasi-steady interaction (that is, unsteady Euler calculation with steady-state boundary-layer calculation).

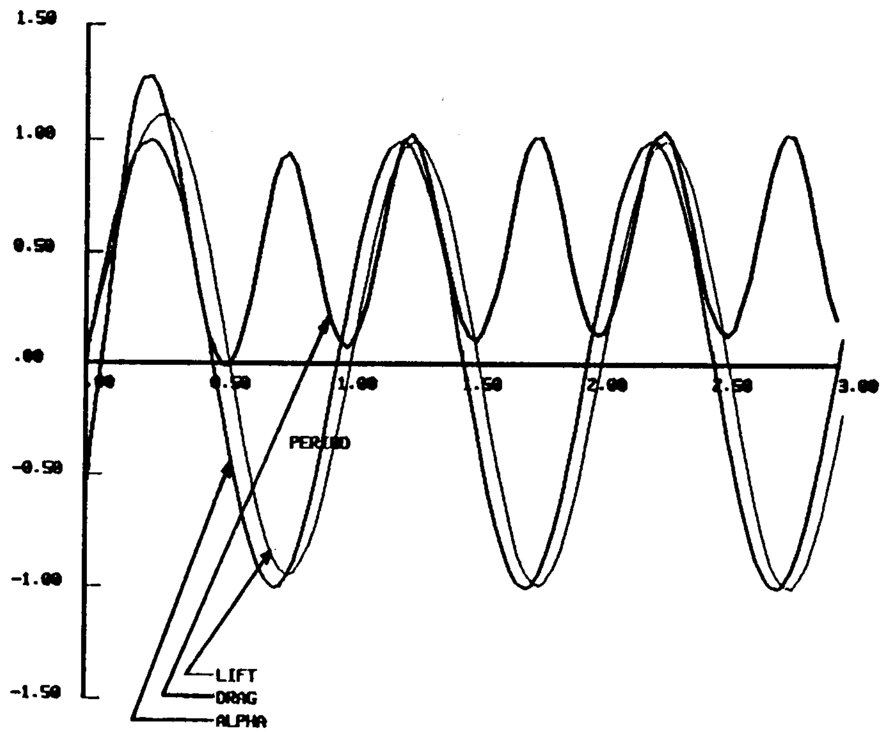

Fig. 7 Quasi-steady interaction for an NACA 0012 airfoil oscillating in pitch ± 1 degree about the quarter-chord point for M = 0.776 and Re = 23.7×10^6 at a reduced frequency of 0.3.

Figure 8 is a comparison of absolute values of lift verses period resulting from the quasi-steady interaction solution described in Figure 7 and an unsteady Navier-Stokes solution for the same conditions. The Navier-Stokes solution is courtesy of Bruce Simpson, Eglin Air Force Base, FL.

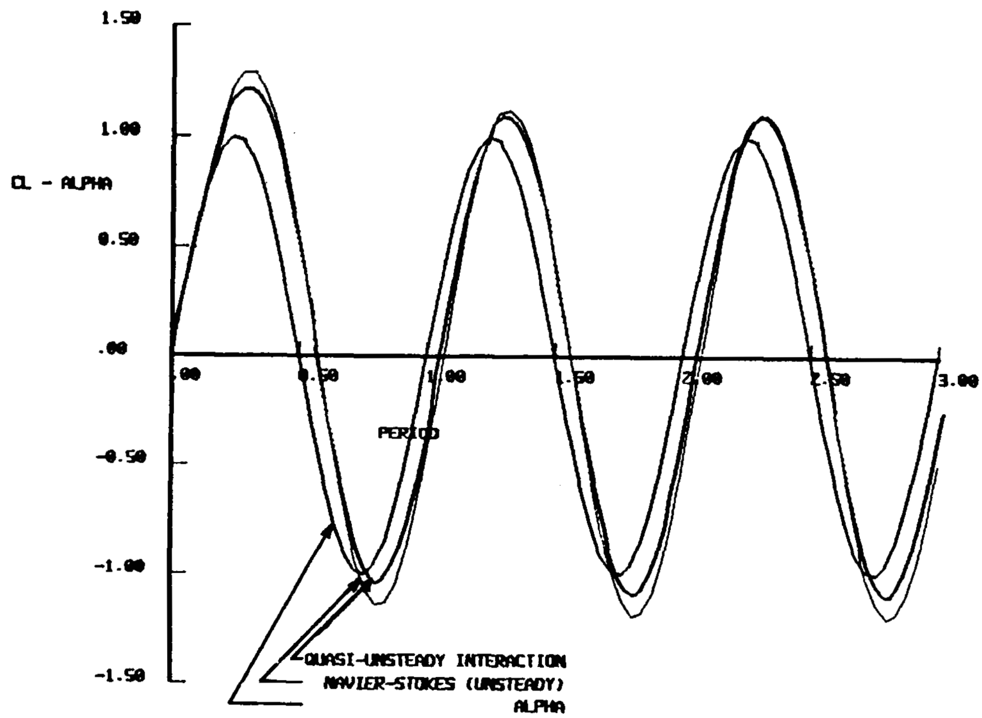

Fig. 8 Lift coefficients for quasi-steady interaction and unsteady Navier-Stokes for an NACA 0012 airfoil oscillating in pitch ± 1 degree about the quarter-chord point for M = 0.776 and Re = 23.7 x 10^6 at a reduced frequency at 0.3.

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CONCLUSIONS

This slide compares some of the advantages and disadvantages of using the Euler and boundary-layer equations for investigating unsteady viscous-inviscid interaction.

ADVANTAGES	DISADVANTAGES
. ENGINEERING ANSWERS	. MUCH MORE DIFFICULT
. FASTER	. SEPARATION (UNSTEADY)
. LESS STORAGE	. DEVOTED LABOR (PARTICULAR EXPERTISE)
. GRIDDING	. COUPLING
	. ROBUST
	. FEWER PEOPLE WORKING THE PROBLEM